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The Activity Demands and Physiological Responses Observed in Professional Ballet: A Systematic Review

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Abstract

The aim of this study was to systematically review research into the activity demands and physiological responses observed in professional ballet. PubMed, Web of Science, SPORTDiscus, and ProQuest were searched for original research relating to 1) the session-specific activity demands of professional ballet, 2) the general activity demands of professional ballet, 3) the immediate physiological responses to professional ballet, or 4) the delayed physiological responses to professional ballet. From an initial 7672 studies, 22 met the inclusion criteria. Methodological quality was assessed using the Mixed Methods Appraisal Tool and a modified Downs and Black Index. Professional ballet is intermittent; however, activity characteristics and intensity vary by session type and company rank. Performances involve high volumes of jumps (5.0 ± 4.9 jumps$\cdot$min^{-1}), *pliés* (11.7 ± 8.4 *pliés*$\cdot$min^{-1}), and lifts (men - 1.9 ± 3.3 lifts$\cdot$min^{-1}), which may result in near-maximal metabolic responses. Ballet classes are less metabolically intense than performance during both barre and centre (< 50% $\dot{V}O_{2max}$). Neither the activity demands nor the physiological responses encountered during rehearsals have been investigated. Day-to-day activity demands are characterized by high volumes of rehearsal and performance (> 5 h$\cdot$day^{-1}), but half is spent at intensities below 3 METs. Evidence is mixed regarding the delayed physiological responses to professional ballet, however, metabolic and musculoskeletal adaptations are unlikely to occur from ballet alone. The mean Downs and Black score was 62%. Appraisal tools revealed that a lack of clarity regarding sampling procedures, no power calculation, and a poor quality of statistical analysis were common limitations of the included studies. Given the large working durations and high rates of jumps, *pliés*, and lifts, managing training loads and recovery may be a focus for strategies seeking to optimize dancer health and wellbeing. Ballet companies should provide dancers with opportunities and resources to engage in supplementary physical training. Further research is required into the physical demands of rehearsals and the longitudinal training loads undertaken by professional ballet dancers.

Keywords: Physiology, Dance, Performance, Injury & Prevention.

1 Introduction

Ballet is a performance art in which dancers express an idea or narrative through movement of the human body. A ballet dancer's movement is founded in classical technique, characterized by vertical alignment of the body, minimal displacement of the pelvis from a central position, external rotation of the lower limbs (i.e., turnout), and extension through joints of the lower body.[1] Whilst historically ballet dancers may have been perceived solely as performing artists, increasingly ballet professionals are considered artistic athletes,[2] facing comparable physical demands to elite sportspeople. Ballet has been compared to aesthetic sports such as gymnastics,[3] with which it shares classically based movement sequences and extreme ranges of motion. The activity profile of ballet performance, however, appears to be similar to sports such as tennis[4] or basketball;[5] ballet is intermittent, involving bouts of high intensity movement, as well as lower intensity periods during which dancers may be acting or off-stage.[6]

Injury incidence in professional ballet (4.4 time-loss injuries per 1000 h)[7] is comparable to that observed in sports such as cricket match-play (1.9–3.9 injuries per 1000 h)[8] and association football training (4.1 injuries per 1000 h).[9] As a result, there have been calls for ballet companies to adopt more robust approaches to science and medical provision.[10] The periodization of workload,[11] implementation of screening protocols,[12] increased strength and conditioning provision,[3] and introduction of specialized healthcare services[13] have been proposed as potential methods of mitigating injury risk. The development of science and medicine provision in professional ballet, however, requires a thorough understanding of the physical demands of the activity. A systematic review is therefore needed to synthesize research into the physical demands of professional ballet, making the evidence accessible to those working in the field, and providing guidance for future research.

The purpose of this systematic review was therefore to identify, evaluate, and summarize research on the activity demands and physiological responses observed during professional ballet, and provide recommendations to direct future investigations.

2 Methods

2.1 Design and Search Strategy

The systematic review was conducted in accordance with the Preferred Reporting Items of Systematic Reviews and Meta-analyses statement.[14] A systematic search of the electronic databases SPORTDiscus, Web of Science, ProQuest, and PubMed (MEDLINE) was performed for scientific literature published prior to January 2021. The following Boolean phrase was used to search each database: (Ballet* OR Ballerin* OR dancer OR dancing) AND (demand* OR response OR responses OR intensity OR volume OR load OR physical OR cardiovascular OR metabolic OR workload OR physiologic* OR schedule OR jump* OR lift* OR *pointe* OR flexib* OR mobility OR strength OR power OR muscul* OR endurance) NOT Title (collegiate OR elderly OR older OR obesity OR cancer OR disease OR “cerebral palsy” OR education). Results from Web of Science and ProQuest were further filtered to include relevant subject areas only; a full list of excluded subject areas can be found in Supplemental Content 1. Hand-searches of each included study’s reference list and the reference lists of review papers pertinent to the topic were completed to identify further relevant articles.

2.2 Inclusion and Exclusion criteria

Studies were included in the review if they met the following inclusion criteria: (1) Participants were professional ballet dancers; (2) During the study, participants either completed a prescribed ballet session or followed their normal ballet schedule; (3) Data were reported on the activity demands or physiological responses encountered; and (4) The study was written in English. Activity demands were defined as any data pertaining to the volume and/or movement intensity of activity completed by the participant(s). Activity demands were further divided into two subsections: (1) S*ession-specific activity demands* - the activity taking place within a specific session (e.g., the number of jumps completed in a ballet class); or (2) *General activity demands* - activity characteristics not limited to a single session (e.g., the number of jumps completed during a week). Physiological responses were divided into two subsections: (1) *Immediate physiological responses* – those recorded on the same day as the activity; and (2) *Delayed physiological responses* – those recorded on a different day to the activity. To be included, delayed physiological responses must have reported a physiological measurement both pre- and post-ballet activity; studies which measured a physiological characteristic at a single time point were not included. All relevant study designs were included in the review.

Studies were excluded if (1) data were reported on a mixed group of dancers (e.g., ballet and contemporary dancers, professional and non-professional ballet dancers), and data for a professional ballet subgroup could not be extracted, (2) no methodology was provided for variables of interest, (3) data were only reported on injured dancers, or (4) only contractual hours were used as a measure of dance exposure. Data pertaining to hormonal responses related to professional ballet were not included in this review.

2.3 Study Screening

Searches and screening processes were independently conducted by two reviewers. Following the completion of searches, duplicate results were automatically removed, and the remaining articles were screened. Four reviewers met, and discrepancies in included articles were resolved by consensus.

2.4 Data Extraction and Analysis

Data were extracted from each study by the lead reviewer. For each study, publication details (author, year, journal) and demographic data (age, height, weight, sex, ballet company, company rank) were extracted. Methodological details (sample size, participant characteristics, session type, study duration, phase of season, equipment, protocol, measurements), and results (descriptive data regarding activity demands and/or physiological responses, results of statistical analyses) were recorded. Data displayed in figures were extracted using WebPlotDigitizer v.4.3.[15] Where further details were required, authors of the study were contacted for clarification. Given the heterogeneity in subject areas and variables reported, a meta-analysis was not conducted.

2.5 Assessment of Methodological Quality

Due to the heterogeneity of study designs used, included studies were evaluated using the Mixed Methods Appraisal Tool (version 2018; MMAT[16]). A modified version of the Downs and Black checklist for the assessment of methodological quality[17] was used to identify more specific strengths and weaknesses of included studies. For each of the criteria, a single point was available (*yes* – 1, *no* – 0, *unable to determine* – 0), except question five, for which two

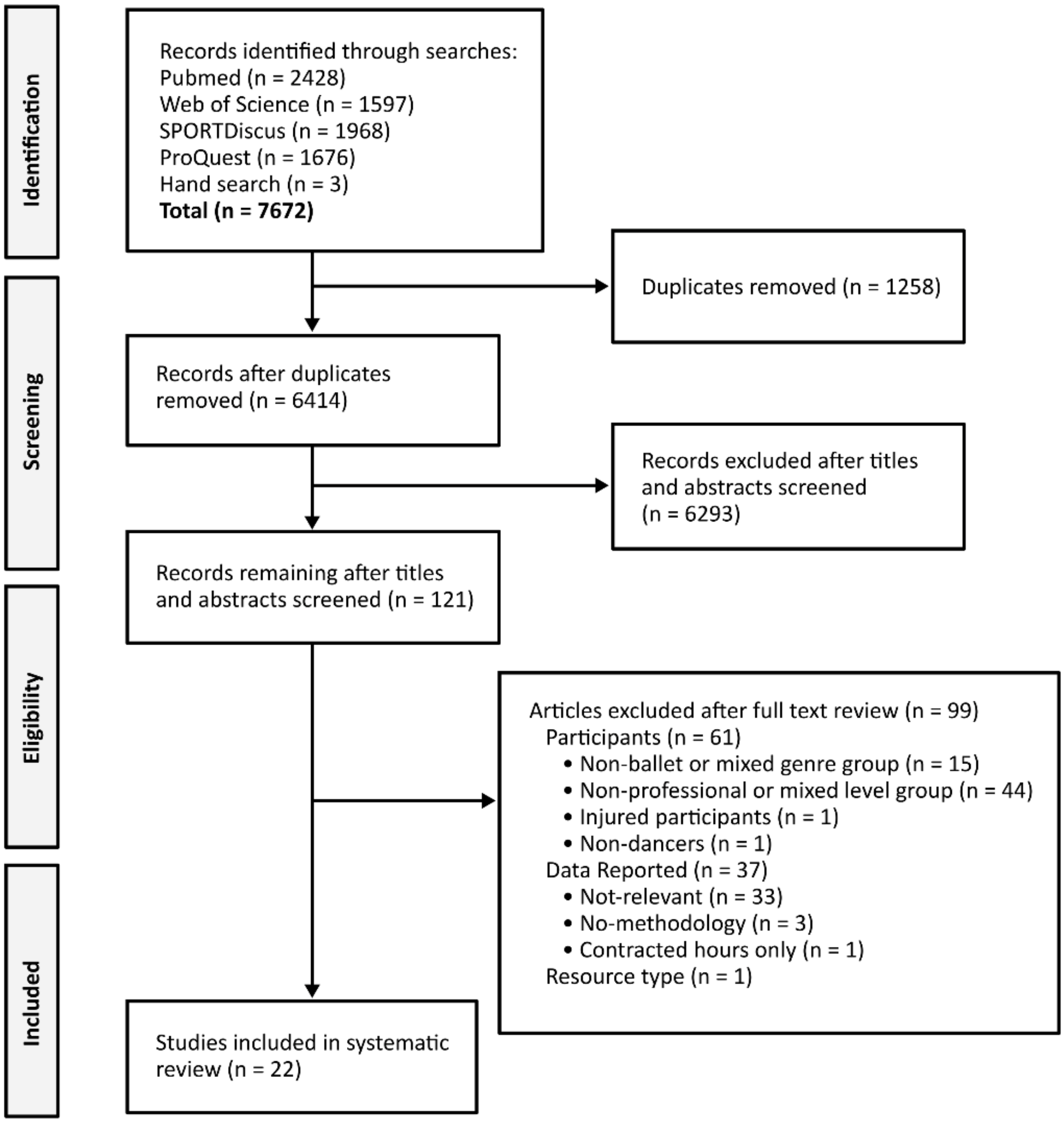

Figure 1. Flow diagram of the systematic search process.

points were available. Question 27 was adjusted to read: “Was a power analysis conducted, and if so, did the sample size provide sufficient statistical power to detect an effect?”. Downs and Black scores were interpreted using the following thresholds: ≤ 50% - *Poor*, 50–70% - *Fair*, 70–90% - *Good*, > 90% - *Excellent*.[18] Risk of bias was assessed at a study level. No articles were excluded based on their methodological quality.

3 Results

3.1 Search Results

The hand-search and search of electronic databases yielded an initial 7672 results of which 1258 were duplicates. Following title and abstract review, 6293 articles were excluded. Full texts of the remaining 121 articles were screened, of which 99 did not meet the inclusion criteria. Twenty-two studies were therefore included in the review. A comprehensive search and selection flow diagram is presented in Figure 1.

3.2 Study Characteristics

Detailed characteristics of each included study can be found in Supplemental Content 2. Five studies investigated session-specific activity characteristics of professional ballet (class: n = 2,[19,20] performance: n = 3[6,21,22]); ten studies investigated the general activity characteristics involved in professional ballet,[7,23–31] four studies investigated the immediate physiological responses to professional ballet (class: n = 2,[19,20] rehearsal: n = 1,[19] performance: n = 3[6,19,32]); eight studies investigated the delayed physiological responses to professional ballet.[30,31,33–38] Five studies used entirely female cohorts, and 17 studies used mixed cohorts.

3.3 Quality Assessment

The mean Downs and Black score was 62%. Five studies were classified as *poor,*[6,19,20,22,32]twelve studies were classified as *fair*,[21,23,37,38,26–28,31,33–36] five studies were classified as *good*,[7,24,25,29,30] and no studies were classified as *excellent*. Full results of the

MMAT and the modified Downs and Black assessments can be found in Table 1 and Supplemental Content 3, respectively. All studies presented a clear research question, and collected data allowing them to address the question. Articles were most commonly marked down due to a failure to sufficiently explain sampling procedures.

Table 1. Results of the Mixed Methods Appraisal Tool assessment of methodological quality.

Study	Screening[A]		Criteria[B]				
	A	B	1	2	3	4	5
Quantitative descriptive							
Wyon et al.[21]	Y	Y	?	?	Y	N	Y
Twitchett et al.[22]	Y	Y	?	?	Y	N	Y
Schantz & Åstrand[19]	Y	Y	?	?	Y	Y	N
Cohen et al.[20]	Y	Y	?	?	Y	N	Y
Cohen et al.[6]	Y	Y	?	?	Y	N	?
Seliger et al.[32]	Y	Y	?	?	Y	N	N
Costa et al.[23]	Y	Y	Y	?	N	Y	Y
Twitchett et al.[26]	Y	Y	?	?	Y	N	Y
Kozai et al.[25]	Y	Y	Y	Y	Y	N	N
Allen et al.[7]	Y	Y	Y	Y	Y	N	Y
Wyon et al.[30]	Y	Y	?	?	Y	N	Y
Wyon et al.[24]	Y	Y	Y	Y	Y	N	Y
Cohen et al.[27]	Y	Y	?	?	Y	N	Y
Doyle-Lucas et al.[28]	Y	Y	?	?	Y	N	N
Non-randomized							
Allen et al.[29]	Y	Y	Y	N	Y	N	Y
Kim et al.[31]	Y	Y	?	Y	Y	N	Y
Wyon et al.[33]	Y	Y	?	Y	Y	N	Y
Koutedakis et al.[35]	Y	Y	?	Y	N	Y	Y
Kirkendall et al.[36]	Y	Y	?	Y	Y	N	Y
Micheli et al.[37]	Y	Y	Y	Y	Y	Y	Y
Randomized controlled trials							
Ramel et al.[38]	Y	Y	Y	?	Y	N	Y
Koutedakis & Sharp[34]	Y	Y	Y	Y	?	N	?

Y – Yes; N – No; ? – Unable to determine.

[A]**Screening questions:** A) Are there clear research questions?; B) Do the data address the research questions?

[B]**Quantitative descriptive criteria:** 1) Relevant sampling strategy?; 2) Is the sample representative of the target population?; 3) Appropriate measurements?; 4) Is the risk of nonresponse bias low?; 5) Is the statistical analysis appropriate?

Non-randomized criteria: 1) Are participants representative of the target population?; 2) Are measurements appropriate regarding both the outcome and intervention (or exposure)?; 3) Are there complete outcome data?; 4) Are confounders accounted for in the design and analysis?; 5) Is the intervention administered (or exposure occurred) as intended?

Randomized controlled trial criteria: 1) Is randomization appropriately performed?; 2) Are groups comparable at baseline?; 3) Are there complete outcome data?; 4) Are outcome assessors blinded?; 5) Did participants adhere to the intervention

3.4 Session-Specific Activity Demands

3.4.1 Class

Two studies investigated the activity characteristics of ballet class.[19,20] Schantz and Åstrand[20] report class durations of 60 min (30 min effective exercise time), made up of seven barre exercises (28 min, 10 s rest intervals), and five centre-floor exercises (32 min, 2-3 min rest intervals). Cohen et al.[19] report class durations of 75 minutes; movement sequences during barre, centre-floor, and *allegro* phases were 65 s, 35 s, and 15 s, and rest periods were 30 s, 85 s, and 75 s, respectively.

3.4.2 Rehearsal

No studies reported data on the activity characteristics of rehearsals.

3.4.3 Performance

Three studies investigated the activity characteristics of ballet performance.[6,21,22] During 5 roles from *Swan Lake*, *Giselle*, and *Études*, the acts/sections observed varied in duration from 14–43 min, with actual dance times ranging from 2–12.5 min (14–30% of performance).[6] During successive variations, work-to-rest ratios of between 1:1.6 and 1:3.4 were observed.[6] Across 48 classical roles,[21,22] over half of the performance time was found to be spent at resting intensities (i.e. still or off-stage), and around a quarter at moderate or hard intensities. Male and female dancers performed jumps (5.0 ± 4.9 jumps·min^{-1}) and *pliés* (11.7 ± 8.4 *pliés*·min^{-1}) at similar rates, though males were involved in lifting their partners (1.9 ± 3.3 lifts·min^{-1}), whilst females were not.[21,22]

3.5 General Activity Characteristics

Ten studies reported data on the general activity demands undertaken by professional ballet dancers;[7,23–31] activity demands were the primary outcome of only 2 of these studies.[25,26] The results of studies reporting durations of physical activity, dance exposure, and supplementary training are presented in Figure 2.

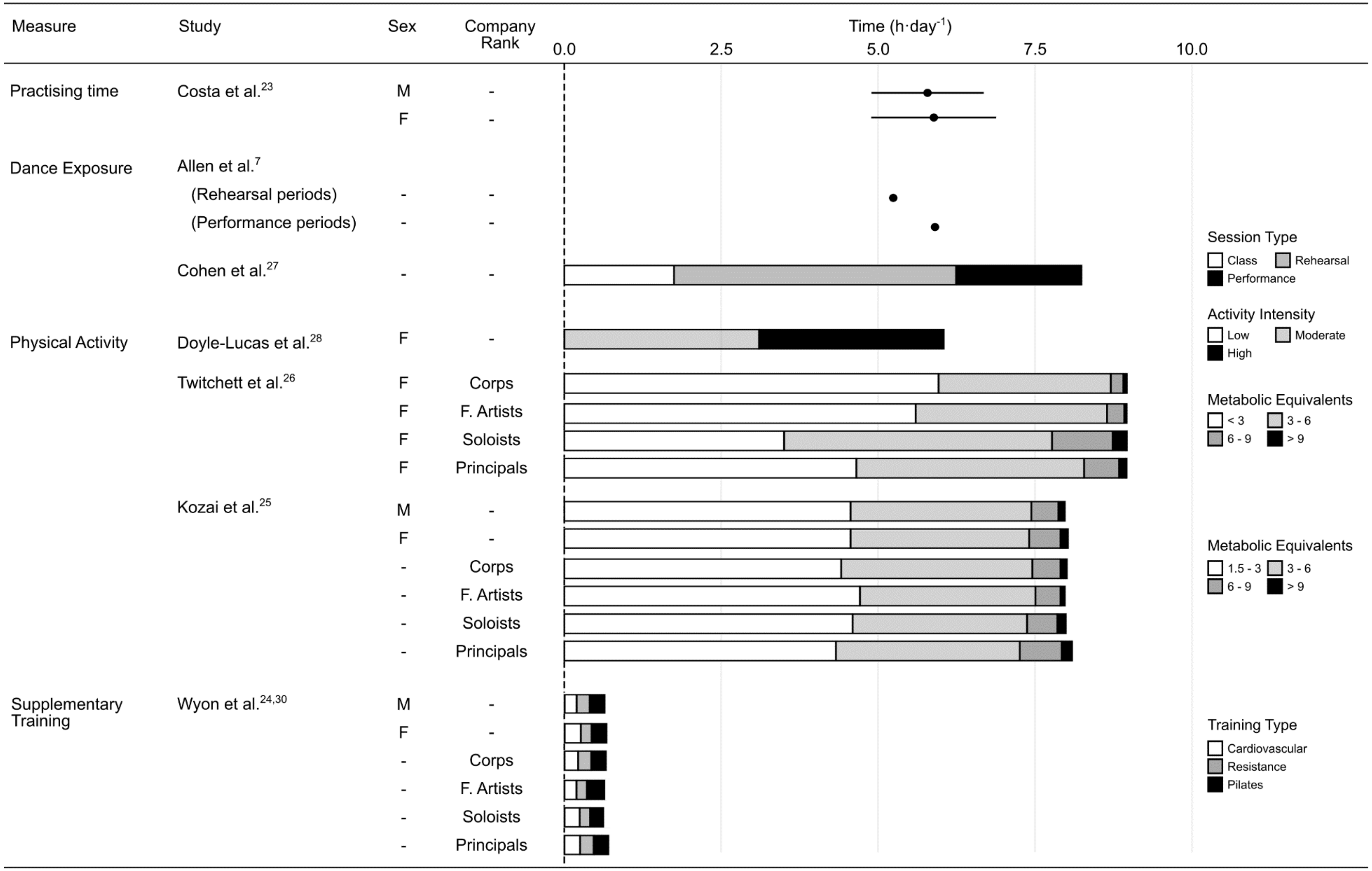

Figure 2. Overviews of studies reporting durations of physical activity, class, rehearsal, performance, or training undertaken by professional ballet dancers. Exposure reported in hours per week is converted to daily exposure assuming a 6-day week. *F.Artists* – First Artists; *M* – Male; F – Female.

Two studies investigated rest periods throughout the working day, reporting mean greatest rest breaks of 36 ± 31 min[26] and 35 ± 27 min.[25] One study describes daily self-reported energy expenditure of female dancers, which in two separate 7-day periods, was 3,571 ± 466 kcal and 3,154 ± 466.[31] Two studies of the same company reported data relating to workload beyond the demands of a single week.[7,29] The company performed between 142 and 145 shows per year, spanning between 15 and 20 productions per year.[29] The first of those seasons was 46 weeks long, consisting of 26 rehearsal weeks and 20 performance weeks.[7] Performance periods were 2–6 weeks in length, during which the company averaged 7 performances per week. The summer break was 5 weeks, and there was a 1-week break at mid-season.

3.6 Immediate Physiological Responses to Professional Ballet

3.6.1 Ballet Class

Two studies investigated the acute physiological responses to ballet class.[19,20] Mean heart rate (66 vs 76% maximum),[20] oxygen uptake ($\dot{V}O_2$; 38 vs 49% $\dot{V}O_{2max}$;[20] 36% vs. 45% $\dot{V}O_{2max}$[19]), and energy expenditure (4.7 vs. 6.3 kcal·min^{-1})[20] were greater during centre-floor exercises than barre exercises. Little change in blood lactate concentration ([BLa]) was seen between barre, centre-floor, and *allegro* phases of class (2.8 vs. 2.8 vs. 3.1 mmol·L^{-1}, respectively).[19]

3.6.2 Rehearsal

One research group[19] investigated the acute physiological responses to (non-performance) choreographed variations or *pas de deux*. Mean $\dot{V}O_2$ was 80 ± 7% of $\dot{V}O_{2max}$ (69-92% of $\dot{V}O_{2max}$), whilst mean post-activity [BLa] was 9.9 ± 3.1 mmol·L^{-1} (6.2-15.2 mmol·L^{-1}).

3.6.3 Performance

Three studies investigated the physiological responses to professional ballet performances.[6,19,32] Mean heart rates during performance were 134[32] and 169 bpm (87%

maximum),[6] and mean peak heart rates were 177[32] and 184 beats·min^{-1} (94% maximum).[6] One study[19] simply states that heart rates during performance were frequently close to maximum, peak [BLa] were similar to those observed following maximal cycling (~11 mmol·L^{-1}), and mean post-performance $\dot{V}O_2$ for two dancers was 85% of $\dot{V}O_{2max}$. One research group[32] reported an increase in both systolic (131 to 172 mmHg) and diastolic (73 to 96 mmHg) blood pressure from pre- to post-performance.

3.7 Delayed Physiological Responses to Professional Ballet

Delayed physiological responses to professional ballet have been reported in 7 studies,[31,33–38] the results of these studies are presented in Table 2. In 4 studies,[31,35–37] the primary aim was to investigate a response to ballet, whilst in 3 studies, [33,34,38] the primary aim was to investigate the effect of an intervention (vitamin D supplementation,[33] strength training,[34] and cardiovascular training[38]), and consequently data for this review were taken from control groups.

4 Discussion

This is the first systematic review to synthesize research exploring the activity demands and physiological responses observed in professional ballet. A total of 22 articles were identified, spanning the subcategories of immediate and delayed physiological responses, and session-specific and general activity demands. We aimed to provide a summary to inform current practice in professional ballet companies, as well as identify gaps in the current body of literature, providing direction to researchers working within this field.

4.1 Session-Specific Physical Demands of Professional Ballet

Ballet is an intermittent activity, though the intensity of that activity varies by session-type. High intensity activity takes place during the latter phases of ballet class,[20] however, the short duration of these bouts, and large inter-exercise rest periods limit the metabolic intensity of the session.[19,20] Ballet performance is of a greater metabolic intensity; bouts of dancing are longer in duration[6] and are higher in both average and peak intensity.[6,19,32]

Table 2. Overviews of studies reporting data on the delayed physiological responses to professional ballet.

Measure	Study	Methods	Timepoints	Results
Body composition	Koutedakis & Sharp[34]	Body mass; skinfold thickness (4 sites); thigh circumference.	(1) Mid-January. (2) + 12 weeks.	No significant differences.
	Kirkendall et al.[36]	Hydrostatic weighing.	(1) Pre-season (August). (2) December	No significant differences.
	Micheli et al.[37]	Body mass; skinfold thickness (7 sites).	(1) Preseason (August). (2) Postseason (May)	In females, body mass (51.6 ± 4.6 kg to 50.4 ± 4.5 kg, $p < .001$) and BF% (12.8 ± 2.7% to 11.5 ± 2.1%, $p < .001$) decreased. No significant differences seen in males.
	Kim et al.[31]	Body mass; bioelectrical impedence.	(1) 7 days pre- (2) 7 days-post a 3-day performance period.	Significant increases were seen in BMI (+ 0.12 $kg{\cdot}m^2$, $p = .032$), LBM (+ 0.5 kg, $p = .002$), and TBW (+ 0.2 L, $p = .021$), but not in body mass or BF%.
	Koutedakis et al.[35]	Skinfold thickness (4 sites).	(1) Post-season. (2) Pre-season. (3) + 2-3 months	No significant differences.
Lower-body strength/power	Koutedakis & Sharp[34]	Isokinetic knee flexion and extension.	(1) Mid-January. (2) + 12 weeks.	No significant differences.
	Kirkendall et al.[36]	Isokinetic knee flexion and extension.	(1) August. (2) December	Significant differences in torque only observed at $180°{\cdot}sec^{-1}$ (males + 12%, females + 16%). For males and females, respectively, relative quadriceps torque increased by 3 and 6% for the right leg, and by 9 and 7% for the left leg.
	Koutedakis et al.[35]	Isokinetic knee flexion and extension; Peak Wingate power.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	Knee extension and flexion torques, and peak Wingate power all increased following the summer break.
	Wyon et al.[33]	Isometric knee extension; vertical jump height.	(1) January. (2) May.	No significant differences.
Aerobic Capacity	Koutedakis et al.[35]	Maximal incremental treadmill test (gas analysis).	(1) Post-season. (2) Pre-season. (3) + 2-3 months	$\dot{V}O_{2max}$ ($mL{\cdot}kg{\cdot}min^{-1}$) increased following the summer break (41.2 ± 8.5 to 45.2 ± 7.1), and again following preseason (48.4 ± 6.8).
	Ramel et al.[38]	Maximal incremental cycle test (gas analysis, blood lactate concentration).	(1) Preseason. (2) +10 weeks.	No significant differences in $\dot{V}O_{2max}$, [BLa], workload at 4 $mmol{\cdot}L^{-1}$, or maximum workload.
Anaerobic Capacity	Koutedakis et al.[35]	Wingate mean power.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	No significant differences.
Flexibility	Koutedakis et al.[35]	Hamstring, trunk, and shoulder flexibility.	(1) Post-season. (2) Pre-season. (3) + 2-3 months	Hamstring, trunk, and shoulder flexibility all increased following the summer break.

$\dot{V}O_{2max}$ – Maximum rate of oxygen consumption; [BLa] – Blood lactate concentration; TBW – Total body water; BF% - Body fat percentage.

However, studies investigating ballet performance have not randomly sampled productions or roles, and one research group[19] explicitly states that only moderately strenuous to very strenuous roles were analysed. It therefore appears that current research on the immediate physiological responses to ballet performance is representative of more physically demanding roles. In contrast, video analyses of 48 roles across classical repertoire[21,22] suggest that most of a performance is spent at rest, particularly in the case of non-principal dancers. Only two studies reported the physical demands of specific performance roles;[6,19] greater granularity in this regard may benefit science and medicine staff when preparing dancers for a specific role.

During performance,[21,22] dancers jump at a greater rate than that observed during volleyball[39] or basketball match-play.[40] Whilst average values (5.0 ± 4.9 jumps$\cdot$min^{-1}) alone are high,[21] it is evident from the standard deviation that there is large variation between roles. Recent research in sport has emphasized the importance of preparing athletes for the worst-case-scenarios they may encounter; neither study,[21,22] however, reports the maximum rate of jumping observed. The most physically demanding segments are likely to exceed the values reported.[21] A recent editorial highlighted jump load as an important injury analytic.[41] To this end, almost a quarter of injuries in one professional ballet company have been attributed to jumping movements.[7] The volume and biomechanics of jumping in professional ballet may therefore be important directions for future research, and are potential targets of injury prevention interventions.

No studies were identified investigating the activity demands taking place in rehearsals, and only one study[19] reported data on the immediate physiological responses to rehearsals. Although near-maximal intensity responses were observed,[19] the ‘rehearsals’ were sessions in which dancers completed solo variations or *pas de deux* from classical repertoire, and not rehearsals as they might occur *in situ*. Subsequently, these responses may not be directly comparable to rehearsals, during which dancers may be learning choreography, practicing shorter segments, or stopping frequently to receive technical guidance. The physical demands of rehearsals therefore remain almost entirely unexplored within scientific literature, and no definitive conclusions can be made. This is particularly notable for two reasons; firstly, unlike classes—which follow a consistent structure, and performances—which are strictly choreographed, rehearsals are inherently more variable from day-to-day; secondly, rehearsal makes up most of a dancer's activity.[27] Further research is therefore required to elucidate the demands of ballet rehearsals, enabling science and medicine practitioners to better prepare dancers for their day-to-day demands, and understand the training loads they undertake.

4.2 General Activity Demands of Professional Ballet

Overtraining syndrome and overuse injuries are common in professional ballet dancers—to this end, ballet dancers have suggested the imbalance between load and load-capacity is the underlying cause.[42] Durations of dance exposure reported in included studies vary, though most studies support the notion that dancers complete over 5 h of dance activity per day.[7,23,25–29] To our knowledge, no published research exists demonstrating comparable training and performance exposure times in any other athletic population.[39,43,44] However, whilst scheduled dance time and self-reported activity is high,[7,23,27] accelerometry studies[25,26] suggest that much of a dancer's day may be spent at intensities below 3 METs. Additionally, accelerometry studies revealed that activity profiles vary by company rank. Future research should therefore avoid the use of company-wide exposure hours, and applied science and medicine practitioners should adopt individualized approaches to load management.[7,27–29]

Despite the recent influx of studies publishing data on the longitudinal workloads of athletes within sporting organizations, little research has explored longitudinal workloads in professional ballet. Although two studies[25,26] conducted longitudinal activity monitoring, data are only reported pertaining to the demands of an average day. Furthermore, as data collection periods were only one[25] and three[26] weeks, reported values may not account for changes in activity which may occur as the repertoire changes across the course of a season. Although the count of shows performed by a professional touring company each season (142–145 shows, 15–20 productions) has been reported on two occasions,[7,29] it is not stated in how many of these shows in individual dancers were involved. Further research is warranted exploring the longitudinal training load demands faced by professional ballet dancers.

Thus, the longitudinal performance demands faced by individual dancers are unknown.

Longitudinal activity monitoring in professional ballet may be facilitated by the use of wearable technology. Several studies have been published exploring and/or validating the use of wearable technology in professional ballet;[45–47] however, the application of these devices and algorithms is not yet evident. Ballet companies may face financial barriers to the implementation of wearable technology, however, methods such as session rating of perceived exertion[48] may provide a cost-effective alternative. Whilst cultural barriers to the implementation of load monitoring in dance may also exist, research in other dance genres,[49] and at a non-professional level,[50] suggests load monitoring may be of value.

4.3 Delayed Physiological Responses to Professional Ballet

It has previously been suggested that participation in ballet alone is insufficient to elicit meaningful physiological adaptation;[24,34] included studies reported mixed results in this regard. Increases in lower limb strength[35,36] and aerobic capacity[35] have been demonstrated following a ballet preseason, though the validity of the changes in one study[35] are hard to determine, as only a subset of the participants were investigated following the preseason. Furthermore, in both studies the initial performance level was indicative of an untrained population and increases in performance were relatively small. Several studies have observed no differences in lower-body strength,[33,34] lower-body power,[33] aerobic capacity,[38] or anaerobic capacity[35] following a professional ballet schedule. The identified studies therefore concur with several cross-sectional studies of professional ballet dancers, reporting aerobic capacities comparable to non-endurance trained athletes,[20,24] and lower-limb strength values below those of other athletic populations.[36] It therefore seems likely that supplementary physical training is needed to elicit significant physiological adaptation.

An improvement in physical performance following the end of a ballet season has been demonstrated by one group of researchers,[35] in which lower-body strength, lower-body power, flexibility, and aerobic capacity all improved following a six-week summer break. Detraining effects might typically be expected following the cessation of the season.[51] Instead, an improvement in physical performance may be indicative of recovery from non-functional overreaching, or overtraining syndrome,[52] which may relate the high volumes of physical work completed in ballet companies.[27] Future research involving concurrent measurements of workload and physical performance across the course of a season may be helpful in further elucidating this relationship.

Investigations into changes in body composition in response to professional ballet reported mixed results. Three studies observed no changes in body composition,[34–36] one saw small increases in lean body mass over a 17-day period,[31] and another saw decreases in body mass and body fat percentage over the course of a season.[37] There was, however, some evidence suggesting female dancers were not adequately meeting their nutritional requirements,[31,37] consistent with previous cross-sectional research in this population.[53] Two included studies also identified the limited opportunity dancers are given to refuel throughout the working day.[25,26] Dancers have previously been identified as an at-risk group for relative energy deficiency in sport.[54] Given the potential consequences for multiple physiological systems, and for both health and performance,[54] ballet companies should ensure they are facilitating screening and monitoring processes and promoting good day-to-day nutritional practices or guidelines.

4.4 Methodological Quality

Only five of the 22 studies were classified as *good*, and no studies were classified as *excellent* following the Downs and Black assessment. Similarly, only one study[37] received a ‘yes’ across all of the five criteria outlined in the MMAT. The most common reason that studies were marked down was the lack of description of the method used to sample participants. Most studies appear to have used a convenience sample of dancers from a single ballet company. When generalizing results to another company, the reader should therefore consider the degree of similarity between the company on which the study was completed, and the company to which the results are being extrapolated. Ballet companies are likely to differ widely in factors such as their size, repertoire, and touring schedule, all of which may influence the physical demands faced by dancers. For studies which investigated the demands of performance roles,[6,21,22] it is difficult to ascertain the extent to which the measured roles are representative of all roles. The potential researcher bias stemming from a lack of random sampling should also be considered, as researchers may have consciously or unconsciously chosen to analyze more physically demanding roles.

The quality of analysis across the included studies was inconsistent. Only two[25,28] of the 22 included studies included a power calculation, and 8[6,19,20,25,28,32,37,38] studies used inappropriate or no statistical analyses. Fifteen studies did not include confounding factors in their analysis; this was most often a failure to account for the dancers' company ranks. Those authors who included company rank as a covariate observed significant differences across levels.[7,21,22,25,26]

Due to the mixed quality of included studies, the heterogeneity of subject areas, and the lack of replicated studies, few findings are supported by strong levels of evidence. Ballet staff and researchers should consider the number and quality of studies supporting an outcome when implementing findings.

4.5 Limitations

Four databases, the reference lists of included studies, and the reference lists of relevant review articles were searched to conduct a comprehensive literature search. However, it is possible that we did not identify studies from journals which are not indexed. Given the artistic nature of the field, we also acknowledge that much of the knowledge regarding the physical demands faced by professional ballet dancers is published in non-scientific literature. Furthermore, as only published research was included, this review may be limited by publication bias. We were also unable to include articles not written in English; given the popularity of ballet around the globe this may have led to the exclusion of relevant articles. Finally, whilst standardized templates were used, only one reviewer completed data extraction and critical appraisals.

4.5 Practical Applications and Further Research

The results of this review reinforce previous suggestions that professional ballet dancers should be considered athletes. Most notably, dancers complete large durations of rehearsal and performance, during which the are required to complete intermittent activity of mixed intensities, characterized by frequent jumps, *pliés* and lifts. Science and medicine practitioners working in professional ballet companies should implement strategies to alleviate the increases in injury risk that may be associated with these demands. For example, encouraging appropriate nutrition and rest following performance, managing dancer training loads, and developing physical characteristics such as strength, power, and aerobic and anaerobic capacity. Given that ballet activity alone does not appear to elicit meaningful physiological adaptations, professional ballet companies should ensure they are providing both the opportunities and resources for dancers to engage in supplementary physical training.

Several key areas of research have not yet been investigated. Research into the session-specific demands of professional ballet has failed to address rehearsals and has not adequately investigated the demands of performance. Understanding these demands more thoroughly may aid in the periodization of repertoire and rehearsals, and provide direction to the physical preparation of dancers. Despite the prominence of *pointe* work in the movement of female dancers, and its implication in foot and ankle injury risk,[55,56] no studies were identified investigating *pointe* activity during any session type. Finally, whilst several studies identified the large training loads undertaken by dancers as a key physical demand, no studies have investigated how these training loads fluctuate based on the time point in the season or the production being rehearsed or performed. Furthermore, only global measures of activity (e.g., duration, physical activity level) have been used to quantify training loads—

several studies[45–47] have demonstrated the use of wearable sensors to provide more detailed insight into the musculoskeletal demands of ballet, though these have yet to be used in professional ballet research.

5 Conclusions

This study systematically reviewed research investigating the physical demands of professional ballet. Professional ballet activity is characterized by frequent jumps, *pliés*, and lifting movements, as well as high rehearsal and performance exposure time. To ensure dancers are physically prepared for these demands, ballet companies should provide opportunities and resources for supplementary physical training. Future research should focus on the physical demands of rehearsals and the longitudinal training load characteristics of professional ballet. There is a need for greater methodological rigour in this field of research, particularly regarding analysis of data and sampling procedures.

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Supplemental Content 1. Included and excluded subject areas in the searches of *Web of Science* and *ProQuest*.

Web of Science

Included

Sport Sciences, Nutrition Dietetics, Dance, Rehabilitation, Neurosciences, Music, Public Environmental Occupational Health, Engineering Biomedical, Medicine General Internal, Physics Applied, Hospitality Leisure Sport Tourism, Psychology, Social Sciences Biomedical, Multidisciplinary Sciences, Surgery, Theater, Biochemistry Molecular Biology, Physiology, Psychology Biological, Medicine Research Experimental, Physics Multidisciplinary, Biology, Biophysics, Endocrinology Metabolism, Health Care Sciences Services, Primary Health Care, Orthopedics.

Excluded

Communication, Psychology Social, Computer Science, Software Engineering, Cultural Studies, Computer Science Theory Methods, Literature, Criminology Penology, Area Studies, Economics, Education Scientific Disciplines, Education Educational Research, Environmental Sciences, Environmental Studies, , Geography, Evolutionary Biology, Management, Women's Studies, Astronomy Astrophysics, Psychology Experimental, Radiology Nuclear Medicine Medical Imaging, Cell Biology, Psychology Multidisciplinary, Religion, Law, Asian Studies, Business, Family Studies, Humanities Multidisciplinary, Engineering Electrical Electronic, Physics Nuclear, Anthropology, Entomology, Art, Chemistry Physical, Sociology, Computer Science Artificial Intelligence, Film Radio Television, Behavioral Sciences, Oncology, Genetics Heredity, Geriatrics Gerontology, Psychology Developmental, Computer Science Cybernetics, Social Sciences Interdisciplinary, Substance Abuse, Linguistics, Zoology, Political Science, Psychology Clinical, Computer Science Information Systems, Social Issues, Ecology, Integrative Complementary Medicine, Urban Studies, History, Obstetrics Gynecology, Biotechnology Applied Microbiology, Gerontology, Health Policy Services, Materials Science Multidisciplinary, Psychology Applied, Philosophy, Pharmacology Pharmacy, Rheumatology, Engineering Mechanical, Pediatrics, Computer Science Interdisciplinary Applications, Instruments Instrumentation, Psychiatry, Clinical Neurology, Language Linguistics, Robotics.

ProQuest

Included

Theater, Studies, Dance, Humans, Research, Dancers & Choreographers, Experiments, Hypotheses, Researchers

Excluded

Politics, Poetry, Literary Criticism, Art, Motion Pictures, Music, Books, Novels, Culture, Women, Drama, Writers, Philosophy, Musicians & Conductors, Actors, Musical Performances, Motion Picture Directors & Producers, Audience, History, Religion, Aesthetics, Essays, Feminism, Animals, Narratives, Reading, Poets, Linguistics, Writing, Creativity, African Americans, Cultural Identity, Male, Female, Literature, Audiences, Fiction, Ideology, Gender, Theory, Language, Society, Opera, Sexuality, Children, Females, Traditions, Collaboration, Films, Animal Behavior, Behavior, Ethics, Semantics, Brain, Consciousness, Composers, 20th Century, Violence, Christianity, Cognition & Reasoning, Algorithms, Adult, 19th Century, Metaphor, Motion Picture Criticism, War, Archives & Records, Modernism, Historical Text Analysis, Memory, Neurosciences, Proteins, Bees, Emotions, English, Sound, Artists, Painting, Computer Simulation, French Language, Popular Music, Self Concept, Spirituality, Postmodernism, Race, Communication, Psychology, Television, Semiotics, 18th Century, Social Networks.

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Supplemental Content 2. Characteristics of included studies.

Study	Design	Participant Characteristics					Activity Demands		Phys. Responses		Common Dataset
		n	Age (y)	Height (m)	Mass (kg)	BMI (kg/m²)	Session	General	Immediate	Delayed	
Wyon et al.[21]	Cross-sectional	24 M 24 F	- -	- -	- -	- -	•				1
Twitchett et al.[22]	Cross-sectional	24 M 24 F	- -	- -	- -	- -	•				1
Schantz & Åstrand[19]	Cross-sectional	6 M 7 F	28 ± 6 25 ± 8	1.80 ± 0.04 1.66 ± 0.55	70.0 ± 4.0 52.0 ± 5.0	- -	•		•		
Cohen et al.[20]	Cross-sectional	7 M 8 F	24	1.78 1.66	68.0 49.5	- -	•		•		
Cohen et al.[6]	Cross-sectional	6 M 7 F	25 ± 3 24 ± 4	1.76 ± 0.03 1.66 ± 0.03	63.9 ± 1.5 48.9 ± 3.9	- -	•		•		
Seliger et al.[32]	Cross-sectional	3 M 3 F	31 ± 8 35 ± 12	1.81 ± 0.06 1.64 ± 0.05	72.3 ± 6.7 53.3 ± 4.1	- -			•		
Costa et al.[23]	Retrospective descriptive	22 M 31 F	34 ± 7 34 ± 6	- -	- -	23.6 ± 1.1 19.5 ± 1.1		•			
Twitchett et al.[26]	Cross-sectional	51 F	28 ± 5	1.61 ± 0.03	46.1 ± 4.5	-		•			
Kozai et al.[25]	Cross-sectional	25 M 23 F	26 ± 5 27 ± 5	1.78 ± 0.04 1.63 ± 0.04	70.7 ± 5.6 49.5 ± 4.9	22.3 ± 1.3 18.5 ± 1.4		•			
Allen et al.[7]	Incidence study	25 M 27 F	23 ± 5 25 ± 6	1.80 ± 0.04 1.62 ± 0.04	71.7 ± 4.7 49.2 ± 4.0	22.2 ± 1.4 18.9 ± 1.6		•			
Allen et al.[29]	Pre-post	27 M[A] 28 F[A]	24 ± 4 25 ± 5	1.79 ± 0.04 1.63 ± 0.03	71.7 ± 5.5 49.9 ± 4.6	- -		•			
Wyon et al.[30]	Cross-sectional	21 M 21 F	- -	1.81 ± 0.04 1.66 ± 0.03	69.5 ± 5.6 50.9 ± 4.5	21.3 ± 1.4 18.5 ± 1.4		•			2
Wyon et al.[24]	Cross-sectional	21 M 21 F	- -	1.81 ± 0.04 1.66 ± 0.03	69.5 ± 5.6 50.9 ± 4.5	21.3 ± 1.4 18.5 ± 1.4		•			2
Cohen et al.[6]	Cross-sectional	15 M 15 F	24 ± 4 23 ± 4	1.77 ± 0.05 1.65 ± 0.04	66.5 ± 4.8 49.6 ± 3.9	- -		•			
Doyle-Lucas et al.[28]	Cross-sectional	15 F	24 ± 1	- -	- -	18.9 ± 0.2		•			
Kim et al.[31]	Pre-post	43 F	26 ± 3	1.64 ± 0.04	49.4 ± 4.4	18.4 ± 1.0		•		•	
Wyon et al.[33]	Non-randomised controlled trial	2 M 5 F	28 ± 0 27 ± 5	1.79 ± 0.02 1.64 ± 0.02	66.5 ± 0.4 50.7 ± 6.5	- -				•	
Koutedakis & Sharp[34]	RCT	22 F	25 ± 1	-	45.0 ± 4.5	-				•	
Koutedakis et al.[35]	Pre-post	17 F	27 ± 1	1.60 ± 0.06	-	-				•	
Kirkendall et al.[36]	Pre-post	14 M 14 F	25 ± 3 24 ± 4	1.78 ± 0.06 1.67 ± 0.07	67.2 ± 8.3 53.9 ± 6.1	- -				•	
Micheli et al.[37]	Pre-post	29 M 39 F	24 ± 6 22 ± 4	- -	71.6 ± 6.4 51.6 ± 4.6	- -				•	
Ramel et al.[38]	RCT	6 M 4 F	24	- -	- -	- -				•	

[A]Mean sample size across three consecutive seasons
BMI – Body mass index; M – Males; F – Females. RCT – Randomized controlled trial

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Supplemental Content 3. Results of the Downs and Black assessment of methodological quality.

Study	Reporting									Ext. Validity			Bias							Confounding						Power	Score	Criteria	Percentage	Descriptor
	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27				
Costa et al.[23]	1	1	1	1	1	1	0	-	1	1	0	1	-	-	1	-	1	-	0	1	0	-	-	0	-	0	12	19	63%	Fair
Schantz & Åstrand[19]	1	1	1	0	1	1	0	-	0	0	0	1	-	-	1	-	0	-	1	-	0	-	-	0	-	0	8	18	44%	Poor
Cohen et al.[20]	1	1	1	1	1	1	1	-	0	0	0	1	-	-	0	-	0	-	1	-	0	-	-	0	-	0	9	18	50%	Poor
Kozai et al.[25]	1	1	1	1	2	1	1	0	1	1	1	1		-	1	-	0	-	1	-	0	-	-	1	1	1	17	20	85%	Good
Cohen et al.[6]	1	1	1	1	1	0	0	-	0	0	0	1	-	-	-	-	0	-	1	-	0	-	-	0	-	0	7	17	41%	Poor
Doyle-Lucas et al.[28]	1	1	1	1	1	1	1	-	0	0	0	1	-	-	1	-	0	-	0	-	0	-	-	0	-	1	10	18	56%	Fair
Twitchett et al.[28]	1	1	0	0	1	1	0	-	0	0	0	1	-	-	1	-	1	-	0	-	0	-	-	1	-	0	8	18	44%	Poor
Wyon et al.[21]	1	1	0	0	1	1	1	-	0	0	0	1	-	-	1	-	1	-	1	-	0	-	-	1	-	0	10	18	56%	Fair
Micheli et al.[37]	1	1	0	1	1	1	1	0	1	1	0	1	-	-	1	1	0	-	1	-	0	-	-	0	1	0	13	21	62%	Fair
Kirkendall et al.[36]	1	1	0	1	1	1	1	0	0	0	0	1	-	-	1	1	1	-	1	-	1	-	-	0	0	0	12	21	57%	Fair
Twitchett et al.[26]	1	1	1	1	2	1	0	-	0	0	0	1	-	-	1	-	1	-	1	-	1	-	-	1	0	0	13	19	68%	Fair
Wyon et al.[24]	1	1	1	1	2	1	1	-	0	1	1	1	-	-	1	-	1	-	1	-	1	-	-	1	-	0	16	18	89%	Good
Allen et al.[29]	1	1	1	0	1	1	1	-	1	1	1	1	-	-	1	1	1	0	1	-	1	-	-	0	0	0	15	21	71%	Good
Seliger et al.[32]	1	1	1	0	1	1	1	-	0	0	0	1	-	-	-	-	0	-	1	-	0	-	-	0	-	0	8	17	47%	Poor
Allen et al.[7]	1	1	1	1	2	1	1	0	0	1	1	1	-	-	1	1	1	-	1	-	1	-	-	1	1	0	18	21	86%	Good
Kim et al.[31]	1	1	1	0	1	1	1	0	1	0	0	1	-	-	1	1	1	1	1	-	1	-	-	0	1	0	15	22	68%	Fair
Koutedakis et al.[35]	1	1	0	1	1	1	1	0	0	0	0	1	-	-	1	0	1	1	1	-	1	-	-	0	0	0	12	22	55%	Fair
Ramel et al.[38]	1	1	0	1	1	1	0	0	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0	0	0	15	27	56%	Fair
Koutedakis & Sharp[34]	1	1	0	1	1	1	1	1	0	0	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1	0	16	27	59%	Fair
Wyon et al.[33]	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	0	0	0	1	0	18	27	67%	Fair
Wyon et al.[30]	1	1	0	1	2	1	1	-	0	1	1	1	-	-	1	-	1	-	1	-	1	-	-	1	-	0	15	18	83%	Good
Cohen et al.[27]	1	1	1	1	1	1	1	-	0	0	0	1	-	-	1	-	1	-	1	0	0	-	-	0	-	0	11	19	58%	Fair
Mean	1.0	1.0	0.6	0.7	1.2	1.0	0.7	0.2	0.3	0.4	0.3	1.0	0.0	0.0	1.0	0.9	0.6	0.5	0.9	0.8	0.5	0.7	0.0	0.3	0.5	0.1	12.7	19.4	62%	

Ext. Validity – External Validity. Downs and Black criteria: 1) Clearly described hypothesis; 2) Main outcomes clearly described; 3) Participant characteristics described; 4) Interventions clearly described; 5) Distributions of principal confounders described; 6) Main findings clearly described; 7) Estimates of random variability given; 9) Characteristics of patients lost to follow-up described; 10) Actual probability values reported; 11) Subjects asked to participate were representative of the entire population; 12) Subjects who participated were representative of the entire population; 13) Facilities and equipment were representative of normal practice; 14) Subjects blinded; 15) Investigators blinded; 16) Any data dredging was made clear; 17) Analyses adjusted for follow-up lengths; 18) Statistical tests were appropriate; 19) Compliance with the intervention was reliable; 20) Main outcome measures were valid and reliable; 21) Intervention and control groups recruited from the same population; 22) Subjects were recruited over the same period of time; 23) Subjects randomized to intervention groups; 24) Randomization concealed from subjects and investigators; 25) Adequate adjustment for confounding factors; 26) Losses of patients to follow-up taken into account; 27) A power analysis was conducted, and sufficient power was achieved.